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Art. XVIII.—*The Petrology of the Igneous Rocks near Healesville and Narbethong.*

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(With Plate I.).

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1.—Introduction and Physiography.

The area described in this paper consists chiefly of an elevated series of ancient volcanic rocks, probably Devonian in age. The relief is marked, Mount Donna Buang and other peaks rising to more than 4000 feet above sea-level, whilst the bed of the Yarra at Healesville is less than 300 feet above the same datum. The Silurian sediments on the north side of the Victorian Main Divide which passes through this area, have an average elevation of between 1000 and 1200 feet, but they rise to more than 2000 feet above sea level in places. Within the area described the divide is entirely in volcanic rocks. The northern streams, of which the most important is the Acheron river, flow into the Goulburn river, whilst the southern streams all drain into the Yarra river. Waterfalls are present near the heads of most of the streams. They are principally determined by joint planes in the volcanic rocks, e.g., Stevenson's falls and the Acheron falls. The Meyer's creek falls, however, are of a different nature, being determined by a mass of hornfels with softer unindurated sediments upstream and downstream from the hornfels.

The rocks are usually covered by dense undergrowth, especially so in the valleys, which are often impassable. The soil covering is very deep in places, and hill-slip material is often abundant, rendering geological mapping very difficult. Coarse bouldery gravels are present in the upper reaches of all the streams, and in inaccessible country of this nature they afford valuable information as to the character of the rocks within the watershed of the streams.

The dacitic rocks from this area possess many features in common with the dacites described from Mount Macedon by Professor Gregory,[1] and by Professor Skeats and Dr. Summers.[2] Rhyôlites and pyroclastic rocks of (?) Devonian age are apparently absent at Macedon, although they are present at various points in the Healesville district. It was with the primary purpose of studying these less well-known rocks in the latter area, that the present research was undertaken by the writer.

2.—Previous Literature.

In 1854 Sir A. R. C. Selwyn[3] prepared a geological map of portion of the country to the east and south-east of Melbourne. The Healesville igneous rocks are roughly delineated and referred to as trap. In the accompanying report Selwyn stated that hornblendic granite passed into porphyry near Mount Monda.

In 1894 J. C. Newbery[4] described rocks from the Blacks' Spur and Fernshaw as mica porphyrite and felspar porphyrite respectively.

In 1901 E. G. Hogg[5] briefly described the microscopical characteristics of a granitic rock from the Watts' river aqueduct. He determined it to be a fine-grained granitite composed of felspar, with plagioclase in excess of orthoclase, quartz, biotite, apotite, chlorite, calcite and muscovite.

In 1902 Professor Gregory,[6] in an important contribution dealing with the Macedon igneous rocks, briefly described the allied

1 Vide infra, p. 3.

2 "The Geology and Petrology of the Macedon District." Bull. Vict. Geol. Surv., No. 24, 1912.

3 "The Geology, Paleontology and Mineralogy of the Country situated between Melbourne, Western Port Bay, Cape Schanck, etc." Rep. Geol. Surv. Vict., Nov. 1854.

4 "Descriptive Catalogue of the specimens of Rocks of Victoria, in the Industrial and Technological Museum, Melbourne," 1894.

5 "Petrology of Victorian Granites." Proc. Roy. Soc. Victoria, vol. xiii. (n.s.), 1901.

6 "The Geology of Mount Macedon." Proc. Roy. Soc. Victoria, vol. xiv. (n.s), Pt. ii., 1902.

dacitic rocks from near Healesville. He believed that the dacites were either of late Mezozoic or early Tertiary age, and he stated that "At the northern foot of the Blacks' Spur, the dacites rest on granodiorite." He described the microscopical features of a rock with flow banding from near Lindt's gateway, and concluded that it was a weathered dacite.

In 1904 F. Chapman[1] contributed a few petrological notes on the igneous rocks to the south of the area dealt with in the present paper. He determined a gneissic banded rock consisting of plagioclase (? oligoclase), augite enwrapped by brown hornblende, and hypersthene, from the Don river valley as a granulitic diorite.[2] Brief petrological notes on the granodiorite and dacite are also given.

A. E. Kitson[3] believed that the dacite series was Upper Mezozoic or Lower Cainozoic in age.

In 1908 Professor Skeats[4] summarised certain of the salient features in the petrography of the dacitic rocks near Healesville, Narbethong and Marysville. He determined the volcanic and intrusive rocks to be dacites, quartz porphyrites, quartz porphyries and granite porphyries, and he stated that "At Dandenong Hills, Narbethong, Marysville and the Strathbogie Ranges, the dacites appear to pass, by the increase of quartz and the diminution or disappearance of hypersthene, into quartz porphyries and quartz porphyrites. No sharp junctions have been noticed and it is inferred that the change is a gradual one."

In 1908 J. Easton,[5] of the Victorian Geological Survey, made a rapid survey of the boundaries of the dacite series near Healesville, Warburton, Narbethong, etc. In a brief report mention is made of the presence of normal biotite dacite, tuffs, granodiorite and trachyphonolite. He records finding the latter rock at two points near Warburton, but his determination of the rock is, without doubt, erroneous, as alkaline rocks appear to be entirely absent from this area.

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1 "Excursion to Lauching Place." Victorian Naturalist, vol. xx., No. 9, 1904.

2 In view of Professor Skeats' later work on the relations of the dacites and granitic rocks near Gembrook, it is probable that this rock is a gneissic dacite. Granodiorite and dacite come into relation near the Don river valley.

3 "Excursion to Warburton." Victorian Naturalist, vol. xxii., No. 8, 1905.

4 "The Volcanic Rocks of Victoria." Pres. Add. Sect. C, Aus. Assoc. Adv. Sci., Brisbane, 1909.

5 "Boundaries of Formations between the head of the Acheron and Yea Rivers and the Yarra." Rec. Vict. Geol. Surv., vol. ii., Pt. 4, 1908.

3.—Upper Silurian Sediments.

The basal beds of the Healesville area are a folded series of fairly shallow water marine sediments, consisting chiefly of sandstones and shales. Two fossiliferous conglomerates were found by the writer near Narbethong, one on either side of the main road from Healesville to Marysville. The western conglomerate was seen in densely overgrown country, at a point about one and a-half miles east of the above-mentioned road, and about two miles from St. Fillans. The conglomerate outcrops on a low ridge trending approximately north and south, and is well jointed. It dips east at about 70° and strikes about north and south, and contains numerous poorly preserved fossils. The pebbles are mostly rounded and sub-angular in shape, and consist almost entirely of sedimentary rocks, vein quartz and quartzite being most common, and chert and sandstone relatively uncommon.

The eastern conglomerate is visible along the now disused road from Narbethong to Marysville. It consists of exactly the same types of pebbles as occur in the western conglomerate, and contains casts of fossils, chiefly corals and crinoid stems. The direction of dip of the conglomerate was not determinate, but the sediments near by are west dipping, and presumably the conglomerate also dips in this direction. It seems likely, from the structure of this portion of the area and from the lithological similarity of the two conglomerates, that they are on the same stratigraphical horizon. The abundant pebbles of milky vein quartz are interesting, suggesting the occurrence in Victoria of quartz veins, possibly auriferous, pre-Upper Silurian in age.

The Silurian sediments at, and to the east of Melbourne, strike fairly consistently east of north. Near Healesville, however, the beds swing round and the strike changes to the west of north, and this direction is maintained as far east as Wood's Point. In Healesville township the strata trends N. 20° W. approximately, and dip about 70° to the west. In the northern portion of the area, near Narbethong and Marysville,, the average strike is between 20° and 30° west of north. No explanation is suggested for this change of strike. Clearly the effect is regional and no explanation, involving local causes, e.g., the effect of the intrusion of the igneous rocks, faulting or cross-folding can be valid.

The precise age of these beds is doubtful. Fossils are very rare, and with the exception of the poorly preserved fossils in the above-mentioned conglomerates, and certain plant remains which the writer found in reddish-coloured sandstones and mudstones in the north of the area, no other fossils have been seen or recorded. Mr. Chapman has kindly examined these plant remains for me, and has referred them to Haliserites Dechenianus, Göppert, a fossil characteristic of his Tangilian division of the Silurian, and which is very abundant in the Tangilian beds at Wood's Point. The presence of Haliserites, the occurrence of fossiliferous conglomerates and the general lithology of these beds, all point to a close similarity with the shallow water marine or estuarine beds near Wood's Point. Tangilian marine fossiliferous strata occur at Starvation creek and McMahon's which are approximately on the continuation of the same line of strike as the beds near Narbethong and Marysville. The evidence at hand, therefore, although not conclusive, supports the belief that the sediments to the north of the volcanics near Narbethong are Tangilian, i.e., Upper Silurian, in age. In the absence of fossils from the beds near Healesville nothing definite can be said respecting their age.

Locally, near the intrusions of granodiorite, the sediments have been metamorphosed and changed to hornfels. Such alteration, however, is never very extensive.

Auriferous quartz veins traverse the sediments in places in this area, but none of them have been economically important.

4.—Petrology.

A. Granodiorite.

Granodiorite and granodiorite porphyry occur as small intrusions at several points around the periphery of the extrusive rocks. The most important localities in which these rocks outcrop are Malory's falls; the Maroondah aqueduct, north of Healesville; west of the road from Healesville to Toolangi, near Meyers' falls; Nyora and in the ranges west of Narbethong.

Malory's falls.—At Malory's falls at a height of about 2000 feet above sea level, is found a rather coarse grained, occasionally porphyritic, rock composed of quartz, felspar, biotite and garnet. Numerous pits are developed on the weathered surface of the rock due to the removal of the felspar. Biotite occurs in fine six-sided lustrous plates. Euhedral crystals of pink garnet (almandine) are fairly common. Examined microscopically, the rock is seen to be very similar to the granodiorite described from the Macedon area, by Professor Skeats and Dr. Summers.[1] It is a holocrystalline

1 Op. cit., p. 19.

rock, showing a tendency towards a porphyritic structure. Zoned plagioclase, having a nucleus of oligoclase or oligoclase-andesine, and an outer zone of albite, greatly predominates over orthoclase. Several traverses of this section showed that the ratio of plagioclase to orthoclase was approximately 3 : 1. One plagioclase phenocryst showed a highly sericitised idiomorphic core surrounded by finely zoned pellucid felspar. Orthoclase is present in simply twinned phenocrysts, including a small quantity of microperthitic albite. It is apparently identical with the type present in the neighbouring rhyolites. Titaniferous biotite occurs as deep brown idiomorphic plates. Some of the biotite has been bleached, and rutile needles have separated out in the form of sagenite webs. Pleochroic haloes due to inclusion of zircon are very noticeable in the altered mica. Inclusions of ilmenite are also common. A little muscovite is also present, but it is undoubtedly secondary. Zircon and apatite are common accessories. The garnet crystals, which appear to be homogeneous in hand specimens are seen under the microscope to be greatly fractured and to include unaltered and chloritised biotite, quartz, ilmenite and apatite. Rims of biotite often surround the garnet crystals.

Maroondah aqueduct, north of Healesville.—Granodiorite outcrops on the ridge separating Meyer's creek and Donnelly's creek. The rock is greatly decomposed near the surface, but fresh specimens are obtainable from the tips formed from the rocks taken out in the tunnelling of the above-mentioned ridge for the Maroondah aqueduct. At the western end of the tunnel contorted, steeply dipping Silurian mudstones and shales outcrop. Near the contact the sediments have been changed to hornfels. Xenoliths of metamorphosed sediments are common in the granodiorite near the contact.

In hand specimen the rock is medium and even grained, and consists of colourless quartz, felspar and abundant biotite. Pink garnets are not uncommon. Fine-grained rocks (microgranite or aplite) are occasionally present.

Section No. H100, contact of granodiorite with sedimentary Xenolith, from tunnel in Maroondah aqueduct.—The mineralogical composition of this granodiorite is very similar to that of the rock from near Malory's falls. The felspars, however, are greatly replaced by sericite and carbonates, and the brown biotite crystals are greatly chloritised, and sagenitic webs of rutile have separated out. A fair amount of granular ilmenite occurs throughout the section. Near the contact pyrrhotite makes its appearance in considerable quantities, and the place of the granular ilmenite is taken by a prismatic variety. Laths of clear, zoned, acid plagioclase, apparently albite, are very abundant in the altered rock .

The granodiorites, from the other localities mentioned, are very similar to these rocks described above, and they do not call for further attention.

B.—Dacites.

The major portion of the area described in this paper is covered by a series of fairly normal dacites. They show considerable variation in colour and granularity, although their mineral composition is usually very uniform. Nevertheless, in the dacites from the Blacks' Spur, quartz phenocrysts are abundant and garnet is often present, and hypersthene is apparently wanting, whilst in the dacites from the summit of Mount Juliet and from the ranges at the head of the Acheron river, hypersthene is relatively abundant and macroscopic quartz phenocrysts are absent. Flow structure is rare in hand specimens of the dacites, although not infrequently visible in thin sections of the Blacks' Spur dacite. Vesicles are usually absent, and mineralisers were apparently rare, as these rocks are relatively little altered. These facts, considered in conjunction with the great thickness of these lavas, probably point to a high degree of viscosity for the extruded magma. Numerous xenoliths of fine-grained andesites resembling hornfels, and white porcelainous rocks occur in the dacites from the Blacks' Spur. Lenticular patches of more coarsely crystallised dacite, often rich in garnets, are also common in the finer grained rock from this locality. Jointing is well developed, both in the dacites and in the rhyolites. Sections along Blacks' Spur road in dacite ,and at Archer's Look-out in rhyolite, illustrate this jointing very well. The average specific gravity of the dacites is 2.71. A chemical analysis by Mr. F. Stone of a specimen of dacite from the Blacks' Spur gave the following result :—

SiO_2	65.80
Al_2O_3	16.87
Fe_2O_3	3.97
FeO	1.08
MgO	1.76
CaO	3.16
K_2O	3.45
Na_2O	2.54
H_2O	1.05
MnO	tr.
Total	99.68

The analysis is very similar to many others of Victorian dacites, and calls for no special remarks.

Specimen No. H45, from near the source of the Acheron river, resembles closely the normal dacites described from the Macedon and Dandenong areas. It consists of phenocrysts of zoned plagioclase (labradorite Ab_1 An_1), greatly corroded quartz, biotite, and occasional crystals of hypersthene, in a microcrystalline ground mass composed of quartz, plagioclase, ilmenite and (?) potash felspar. Zircorn and apatite are accessories. Occasional phenocrysts of untwinned felspar may be orthoclase. The biotite phenocrysts have been attacked by the solidifying magma, and as a result they are often fretted and contain internal cavities filled with quartz and felspar. The hypersthene is decidedly pleochroic and includes ilmenite, felspar and biotite. The absorption scheme is as follows :—

X light brown with a trace of pink.
Y brownish yellow.
Z light green.

Sections cut parallel to 010 give a biaxial figure, having a moderately large axial angle. Ilmenite occurs as idiomorphic crystals in the ground mass of the rock, and included in biotite and hypersthene.

Of particular interest is the occurrence in this section of two or three irregular shaped phenocrysts of cordierite showing the characteristic trilling.

One section in particular (vide plate I., figure 4) shows the trilling very finely. The cordierite has a refractive index greater than the balsam ($\mu = 1.532$), and is distinctly biaxial. It is not greatly altered, but contains numerous linearly arranged inclusions in certain cases.

Specimen No. H44, Blacks' Spur road, is typical of the hypersthene free dacites. It consists of phenocrysts of colourless quartz, beautifully zoned plagioclase (chiefly labradorite Ab_1 An_1), and deep brown six-sided biotite in a cryptocrystalline ground mass. Accessory and secondary minerals are garnet, tourmaline, zircon, pyrrhotite, ilmenite or magnetite (?) opal, chlorite, sericite, quartz and sillimanite. Plagioclase phenocrysts are numerous. They are usually well zoned, and show both albite and pericline twin lamellae. Maximum symmetrical extinction angles of about 27° indicate labradorite near Ab_1 An_1. Biotite is greatly chloritised, noticeably so close to the garnet crystals. It is concentrated round the margin of the latter mineral. The garnet is seen under the microscope to consist of irregular granular aggregates, resembling the "siebstructure" of Weinschenck. Inclusions of biotite, pyrrhotite and ilmenite are present in the garnet, and it is associated with secondary quartz, zircon and tourmaline. A few lath-shaped sections are seen of a colourless mineral having moderately high refractive index, but much less than that of zircon, and exhibiting bright pinks and greens of the third order between crossed nicols. The mineral shows straight extinction, and determination of its sign by a quartz wedge proves it to be positive. It is, therefore, undoubtedly sillimanite, although its polarisation colours are rather high for this mineral. Occasional laths of a fibrous, strongly pleochroic (blue or violet to almost colourless) tourmaline, having a negative sign and normal absorption, are present in the section. Apatite and zircon are accessories.

Section No. H73, dacite, from near Donnelly's weir, consists of large fractured phenocrysts of colourless corroded quartz and fairly large plagioclase crystals, showing both Carlsbad and Albite twinning, in a fine-grained pilotaxitic ground mass composed of labradorite laths, chlorite and a little quartz. One or two vesicles, infilled with chlorite and epidote, are present in this rock. Biotite is rare, being greatly chloritised.

Assimilation.—Assimilation of either aluminous sediments or igneous rocks, has undoubtedly occurred to some extent, as is proved by the presence of cordierite, sillimanite and garnet in certain of these rocks. Numerous undigested sedimentary and igneous xenoliths are also seen in the dacites.

A. Bergeat[1] has recently described an interesting case of the melting up and assimilation of an andalusite bearing rock by an andesite, with the formation of cordierite, sillimanite, garnet, biotite, orthoclase and spinel. All these minerals, with the exception of the last named, are present in the Healesville dacites.

Origin of the garnet.—Pink garnet is relatively widespread in (?) Devonian igneous rocks in Victoria. It occurs in granite or granodiorite near Toora, Wilson's Promontory, Mount Taylor, Beechworth, Healesville and elsewhere; and in intrusive and extrusive rocks, porphyries, porphyrites, daxites, etc., from near Mansfield, Strathbogie ranges, Mount Dandenong, Healesville and Warburton. The occurrence of the garnet in these rocks under such

1 "Der cordieritaudesit von Lipari, seine Andalusit führenden einschlüsse und die genetischen veziehungen zwischen dem Andalusit, Sillimanit, Biotit, Cordierit, Orthoklas und Spinell in dem letzteren." Neues. Jaheb. Min. Geol. (Beil. Bd.) 30, pp. 575-627, 1910.

varied conditions, strongly suggests that it is a primary mineral. Although only rarely visible macroscopically in the rocks from the Healesville area, microscopic examination has revealed its presence in granodiorites, dacites, rhyolites, and tuffs. Its occurrence in these rocks (both plutonic and extrusive) certainly suggests that it was an original mineral in the magma from which these rocks were derived. Microscopical examination of these garnet-bearing rocks, however, leads one to doubt the primary origin of the garnet for the following reasons :—

1. The apparently homogeneous crystals of garnet, occurring in hand specimens of the rocks, are seen under the microscope to be aggregates of garnet grains associated with secondary quartz, pyrrhotite, chlorite after biotite, sericitised felspar, and in one case with blue tourmaline.

2. The association of garnet with pyrrhotite and chloritised biotite is characteristic. Rims of pennine occasionally surround the garnet aggregates. Pyrrhotite is often a contact metamorphic mineral, and has been noticed in the altered sediments adjoining granodiorite at the Maroondah aqueduct.

3. Garnet is apparently absent in the hypersthene bearing dacites; at least this is so in all the sections of these rocks that I have examined. Sir Thomas Holland has described certain rocks in which garnet apparently replaces hypersthene, but in our case sufficient evidence is not available to determine whether such replacement has taken place.

Contact metamorphism of the volcanic rocks only becomes marked near certain of the granodiorite intrusions, and garnet is invariably absent from the contact rocks, so that it is improbable that the garnet is a contact metamorphic mineral.

Abyssal magmatic assimilation might possibly account for the presence of the garnet in the Healesville igneous rocks. Cordierite, sillimanite and garnet have been previously mentioned as forming at Lipari owing to the assimilation of an andalusite bearing rock by an andesite.

Summing up, no definite conclusion, respecting the origin of the garnet, can be arrived at, and it is left for future investigators to make a more detailed study of the question.

C.—Andesites.

Quartz free andesites are rarely met with in the Healesville area. The best example of these rocks seen by the writer occurs at a point

1 "Geology of the neighbourhood of Salem, etc." Memoirs Geol. Surv. India, vol. xxx., 1900

about two miles along the Don road, north of Launching Place. The rock is very tough and fine grained, and felspar is the only mineral visible megascopically.

A thin section of the rock examined under the microscope, consisted of phenocrysts of felspar in a fine-grained andesitic ground mass of laths and stunted prisms of plagioclase, microcrystalline quartz and magnetite dust. Chlorite, sericite and epidote (pistacite) are alternation products. Original femic minerals are lacking.

Recrystallisation has taken place in the ground mass of the original rock, and a mosaic of quartz grains has been formed. Occasional vesicles filled with chlorite and quartz are also present. The panidiomorphic plagioclase phenocrysts are well zoned, and give maximum symmetrical extinction angles of 36° from the albite lamellae, indicating plagioclase near labradorite-bytownite (Ab_2 An_3). Most of them are highly sericitised, and a little secondary epidote has been developed in the felspar in places. The ground mass laths are generally only simply twinned and are referable to labradorite.

Section No. H2, from near Wade's Look-out, is a fine-grained andesite consisting of zoned phenocrysts of rather basic labradorite, and chloritised femic mineral, in a pilotaxitic ground mass composed of plagioclase laths, biotite, chlorite and ilmenite. Quartz is absent. The section of this rock is very similar to sections of certain black andesitic xenoliths present in the dacites.

Section No. H79, biotite andesite, M.M.B.W. pipe line to Badger Creek Weir.—A thin section of the rock examined microscopically shows abundant phenocrysts of zoned plagioclase (andesine or acid labradorite), chloritised biotite and ilmenite in a yellowish coloured devitrified glassy ground mass. Quartz is almost entirely absent. Abundant granular ilmenite occurs, included in biotite, and in the ground mass of the rock some of the ilmenite is replaced by pyrites. A little epidote replaces biotite.

D. Pyroclastics.

Section near Wade's Look-out.—The best section of these fragmental rocks, in the area described, occurs in cuttings along the Don road from Healesville to Launching Place, above Wade's Look-out. Near the Look-out, the pyroclastics are seen resting on east-dipping silurian sediments. The former consist here of tuffs, and volcanic agglomerates containing rounded and sub-angular pebbles of rhyolite or quartz porphyry. About one-third of a mile above

Wade's Look-out, two cuttings for road metal have exposed good sections of these fragmental rocks. The following section is seen in one of these cuttings:—

A.—Dense, black, aphanitic ash resembling chert; width about 7 feet.

B.—Coarser grained tuff or ash containing occasional agglomeratic pebbles of rhyolite. It is well bedded, and dips steeply to the east; width about 5 feet.

C.—Partially unconsolidated, finely bedded tuff resembling a mudstone; width about 2½ feet.

Examined under a lens, numerous flakes of biotite and a few grains of quartz and altered felspar, and a little pyrite and muscovite are discernible in the rock. The tuff is ripple marked in places, but it is impossible to determine whether these markings are due to water action or wind. No fossils, either marine or fresh water forms, were found in these tuffs, and they appear to be entirely sub-aerial in origin.

D.—Another band of black, flinty ash.

These pyroclastic rocks all appear to dip at fairly high angles to the east, but they are well jointed and it is possible, but not probable, that jointing and bedding were confused by the author. It is possible that these tuffs and ashes were originally deposited on some fairly steep slope, but the more probable explanation of their high dip is that they have been subjected to later earth movements.

Section No. HI, black cherty ash, referred to above as A.—Under the microscope angular pieces of quartz and occasional fragments of beautifully zoned plagioclase can be recognised in a cryptocrystalline matrix. A little biotite is also present, and finely divided iron oxide is plentiful. Bedding is distinctly visible. The bedding planes, however, are not straight, but occur in the form of waves, suggesting rippling.

Section No. H3, bedded tuff, partially unconsolidated, referred to as D.—Microscopically it consists of numerous angular and oval-shaped fragments of igneous rocks largely dacitic in composition. One or two xenolites of sandstone are present in the section. The bulk of the rock, however, consists of finely-divided rock dust, and fragments of crystals, of quartz, felspar, biotite, chlorite and colourless garnet. The whole of the felspar appears to be plagioclase, and none of the orthoclase, so characteristic of the tuffs near Malory's falls, is present. Chalcedonic silica is well developed in places.

Section No. H30, xenolith in tuff, one-third of a mile above Wade's Look-out.—A leucocratic, porphyritic rock, consisting of phenocrysts of quartz, microperthitic, orthoclase, acid plagioclase and muscovite in a cryptocrystalline ground mass composed of the same minerals. Orthoclase is in excess of plagioclase. The phenocrysts of muscovite usually show included needles and sagenitic webs of rutile, and occasionally include a little epidote. They undoubtedly replace original biotite. Quartz grains are plentiful. They remain clear, although often greatly corroded. Leucoxene is fairly abundant, and one or two twinned sections of epidote are also present. The rock may be described as a quartz porphyry or rhyolite. The presence of the microperthitic orthoclase, so characteristic of the rhyolites, is interesting.

Section No. H15, xenolith in tuff, one-third of a mile above Wade's Look-out.—The rock is an altered quartz porphyry consisting of large phenocrysts of quartz, highly sericitised and kaolinised felspar, and occasional biotite crystals, in a microcrystalline ground mass. The idiomorphic outlines of the felspar and the absence of twinning suggest orthoclase. A little yellowish-brown opal occurs in places, and brown iron oxides are rather common, showing that the rock is much weathered.

Track to Malory's falls.—Tuffs are well developed near the northern foot of the Blacks' Spur, and they can be seen at numerous points along the track from near Lindt's Hermitage to Malory's falls. They are generally light coloured, white or grey, but are occasionally stained with hydrated oxides of iron. Certain of the tuffs still remain loose and cavernous, but the majority have been secondarily silicified and rendered more compact. Cubes of pyrite are common. The lapilli present in the tuffs are usually small, being rarely more than half an inch in diameter. Examined microscopically, these tuffs are seen to consist chiefly of fragments of rhyolitic rocks. Lapilli of sedimentary rocks are very rarely present. Especially characteristic, in these pyroclastics, is the microperthitic orthoclase so abundant in the rhyolite lavas.

Specimen No. H4, track to Malory's falls.—Numerous fragments of banded rhyolite are seen in hand specimens of this rock. Crystals of quartz and altered orthoclase are also visible megascopically. Examined microscopically phenocrysts of altered microperthitic orthoclase, acid plagioclase, and colourless quartz, are immediately recognised. Chloritised biotite occurs in small amount. The matrix of the rock appears to consist largely of microcrystalline silica and sericitised felspar. That secondary silicification has taken place is evident from the silica added to some of the quartz phenocrysts. The rock is a rhyolite tuff.

Section No. H54, from near H4, is again composed almost entirely of rhyolitic debris.—Rectangular sections of muscovite, secondary after biotite, are numerous and clear, simply twinned laths of acid plagioclase are not uncommon. Microperthitic orthoclase occurs as fragments of crystals, much corroded and greatly sericitised in places. The matrix is chiefly finely granular silica, chalcedony, and sericitised felspar. Certain colourless isotropic cubes, of a mineral having a refractive index much less than that of the ground mass, are undoubtedly fluorite.

Section No. H9, track to Malory's falls, is made up of lapilli of andesitic and rhyolitic rocks and fragments of chlorite, secondary after biotite, quartz, plagiolcase, biotite and highly sericitised orthoclase in a matrix composed chiefly of quartz and sericitised felspar. Abundant leucoxene and zircon occur scattered through the section. Microperthitic orthoclase is almost entirely absent. One or two fragments of garnet are also present.

Section No. H39, immediately west of the Blacks' Spur road, on the track to Malory's falls.—Fluorite cubes are again present in this section. The rock is a normal rhyolite tuff.

M.M.B.W. pipe line to Badger Creek Weir, S.S.W. of Mount Riddell.—Ashes, tuffs with fine lapilli, and coarse agglomerates are all present in the rocks from this locality. The agglomerate pebbles are usually small, being rarely more than three inches in diameter, and are mostly sub-angular in shape. They consist almost entirely of a yellowish-green, aphanitic, pyritised rock resembling in hand specimen the Diamond creek dyke rock. No signs of bedding are visible in any of the tuffs. They are frequently honeycombed, and secondary carbonates, sericite and pyrites have been developed in them.

Specimen No. H88, pebble in agglomerate, S.S.W. of Mount Riddell, is a leucocratic, aphanitic rock showing minute grains of quartz, felspar and a little pyrite in hand specimen. Microscopically, it consists of phenocrysts of altered felspar, quartz and a little chloritised femic mineral, in a ground mass of quartz, felspar laths and occasional ilmenite. Carbonates, sericite, chlorite, rutile and leucoxene are secondary minerals. Veinlets of quartz and carbonates traverse the rock. The felspar phenocrysts are predominantly orthoclase; highly sericitised in general and often carbonated. The plagioclase phencrysts are of albite or albite-oligoclase, and are not zoned. The grains of quartz are pellucid as usual, but are often greatly fractured and corroded. The rock is a metasomatically altered rhyolite of quartz porphyry.

Section No. H91, xenolith in tuffs, S.S.W. of Mount Riddell, is a slightly metamorphosed granodiorite. Biotite is greatly replaced by chlorite (pennine) and rutile has separated out as sagenitic webs. Abundant pyrrhotite occurs throughout the section, replacing much of the original ilmenite. The felspars are greatly altered, but plagioclase appears to be in excess of orthoclase.

Section No. H94, andesite tuff, from same locality as preceding specimens. Under the microscope the rock is seen to consist largely of fragments of andesite showing fine pilotaxitic texture. The original biotite crystals have been replaced by strongly pleochroic chlorite (pennine) and epidote (pistacite), and leucoxene has separated out. Quartz phenocrysts are rare, but the bulk of the matrix of the rock appears to be silica, some of which is chalcedonic. Occasional crystals of colourless isotropic garnet are seen in the section. The felspar phenocrysts and ground mass laths appear to be almost entirely plagioclase, often well zoned.

Track to Maroondah weir.—Doubtful fragmental rocks occur near Maroondah weir. Specimen No. J1, metasomatically altered rhyolite tuff or rhyolite, one mile south-west of Maroondah weir, is typical of these rocks. Hand specimens are brecciated, consisting of fragments of a light-coloured rock in a darker coloured matrix. Thin sections of the rock examined microscopically show that silicification, carbonation and sericitisation have greatly affected the original rock. The primary minerals include simply twinned orthoclase, plagioclase, corroded and fractured quartz, garnet, zircon, sphene, apatite and a (?) femic mineral which has been entirely replaced. Muscovite, carbonates (? dolomite), chalcedony, quartz pyrites, (?) opal and brown iron oxides are secondary. Most of the plagioclase has a refractive index less than that of quartz, and appears to be albite, but certain zoned sections give symmetrical extinction angles of 22° from the albite lamellae, indicating andesine. Massive cleaved carbonates and flakes of sericite replace much of the felspar. A little secondary, radially arranged, albite has been developed in one place in the section. Yellow-brown aggregates and double wedge-shaped sections of sphene, showing bright pinks and greens of the third order under crossed nicols, are not uncommon. The garnet is rarely idiomorphic, occurring more often in corroded and irregular-shaped grains. Microspherulitic chalcedony, showing a black cross under crossed nicols, occurs throughout the section. Minute veins of quartz traverse the rock.

Section No. H101, one mile S.W. of Maroondah Weir.—Sharp rhombs of dolomite occur in places, associated with secondary quartz and iron oxides. Microscopic veinlets of banded silica and carbonates intersect the rock.

Fragmental rocks, tuffs and flinty breccias whose fragmental character is only revealed on weathering, also occur to the south and south-west of Mount St. Leonard.

E.—Rhyolites.

With the single exception of Professor Skeats' reference to quartz porphyries and porphyrites occurring near Narbethong and Marysville, there is no mention, in the literature of the area, of extrusive rocks more acid than the dacites. However, at Archer's Look-out, St. Ronan's Well, near Lindt's Hermitage, the Acheron river above St. Fillan's, and at several other points north of the main divide, normal rhyolites outcrop. These rocks are characterised in hand specimens by abundant quartz phenocrysts, and by the paucity of femic minerals. Rhomb-shaped sections of glassy or pearly orthoclase can be recognised in nearly all hand specimens of these rocks. Fluxion banding is often well developed. A chemical analysis of the rhyolite from Archer's Look-out was made by the writer in the geo-chemical laboratory of the Royal College of Science, London, and gave the following result :—

	I.	II.
SiO_2	74.39	78.64
Al_2O_3	14.28	9.85
Fe_2O_3	0.52	0.54
FeO	1.09	2.00
MgO	0.27	0.10
CaO	0.24	0.80
K_2O	5.33	5.16
Na_2O	2.78	2.03
$H_2O +$	0.22	0.40
$H_2O -$	0.56	0.14
CO_2	abs.	—
TiO_2	0.29	0.67
P_2O_5	tr.	tr.
BaO	n. det.	—
MaO	n. det.	—
Total	99.97	100.33
Sp. Gr.	2.49	

I. Rhyolite, Archer's Lookout. Analyst, N. R. Junner.

II. Rhyolite, Mount Wellington. Analyst, E. O. Thiele.

Using H. C. Richards' analysis of the biotite from the dacite near Mount Dandenong, with slight adjustment of the relative proportions of FeO and MgO to fit the percentages of these constituents in the rock, we can determine approximately the mineral composition of the rock. Thus :—

Quartz	37.20
Orthoclase	29.47
Albite ($Ab_{83}An_4$)	24.69
Biotite	3.65
Magnetite	0.70
Excess Al_2O_3	3.47
Excess H_2O	0.67
Total	99.85

Much of the felspar is changed to kaolin, so that this mineral will account for a certain amount of the surplus Al_2O_3 and H_2O. The percentages of iron oxides, magnesia, and lime are all low, and there is a corresponding small percentage of lime-bearing felspar and femic minerals present in the rock. Microscopical examination shows that the felspar phenocrysts are orthoclase, containing microperthitic inclusions of soda felspar, accounting for the moderately high percentage of soda in the rock.

Microscopical relations.—A section of the rock analysed showed phenocrysts of quartz and kaolinised orthoclase in a microcrystalline ground mass consisting of quartz, orthoclase and biotite. Zircon and apatite are accessories. Secondary minerals include chlorite, kaolin, hematite, sericite and a little biotite, tourmaline and brown opal. A micrometric analysis of the rock showed that the ratio of ground mass to phenocrysts was approximately 1.1 :1. The orthoclase phenocrysts are often idiomorphic and are sometimes rounded by corrosion of the ground mass. They occasionally show the characteristic cross fracture of sanidine. Carlsbad twinning is not uncommon. The phenocrysts of quartz are occasionally hexagonal in section, but are more often rounded and embayed by the ground mass. Numerous cracks and abundant glass inclusions are present in the quartz. Biotite occurs sparingly as phenocrysts, but is abundant in aggregates of minute flakes, in the ground mass of the rock.

Section No. H50, Archer's Look-out, shows phenocrysts of quartz, sanidine, and altered biotite in a microcrystalline ground mass consisting of the same minerals, together with tourmaline, sericite, and a very little ilmenite. The texture is porphyritic. Flow banding is very well developed, yet the ground mass is thoroughly crystalline.

A beautiful blue tourmaline occurs scattered through the section in mossy aggregates. These aggregates examined under the high-power resolve into groups of acicular crystals and hexagonal cross sections of these needles. Pleochroism is very marked, varying from ultramarine to yellowish or greenish-brown. An anomalous feature of this mineral is that its strongest absorption is in the same direction as in biotite, which also occurs in the same section. It seems probable that the tourmaline replaces biotite and that it has retained the original form of the mica.

Minute flakes and prismatic sections of biotite occur throughout the section. These are probably secondary in origin. The original biotite differs from them in having much larger sections, and in its corrosion by the magma and separation of oxides of iron and titanium. A brown, isotropic mineral, having a refractive index less than the balsam and occurring in small amount in the section, is opal. It is fringed with secondary biotite in places.

Section No. H57, Acheron River, above St. Fillans.—This rock consists of phenocrysts of deeply embayed colourless quartz, turbid microperthitic orthoclase, and a little biotite and albite, in a cryptocrystalline ground mass which was originally glassy and microspherulitic. Minute spherulites, preserved in quartz, are not uncommon in the ground mass of the rock. Chlorite and brown iron oxide replace the original femic mineral which was probably biotite. Prisms of tourmaline, showing normal absorption, are associated with chlorite or serpentine in places.

Section No. H49, Acheron River, above St. Fillans.—Aggregates of blue tourmaline showing anomalous absorption are present in this section. The tourmaline occurs associated with muscovite and replaces biotite, whose form it retains. Plagioclase phenocrysts are absent, but a little albite occurs in the ground mass of the rock.

Section No. H67, banded rhyolite from near Malory's falls.—Chalcedonic silica, with nuclei of slightly yellow coloured, apparently isotropic material, having a refractive index much greater than the chalcedony, occurs in places in this section.

Certain obscure flinty rocks occurring near Mount St. Leonard may be best described under the heading of rhyolites, although the writer is quite prepared to admit the possibility of their being silicified tuffs.

Section No. H77, from Meyer's creek road, south-west of Mount St. Leonard, is typical of these rocks. It consists of phenocrysts of quartz and occasional highly sericitised crystals of orthoclase and plagioclase, in a microcrystalline ground mass of quartz, biotite and altered felspar. The structure of the rock is homogeneous. Radial aggregates of secondary biotite have been developed in association with mosaics of secondary quartz and a little pellucid felspar.

Section No. H72, from same locality as the preceding specimen.—Microscopically it consists of occasional phenocrysts of pellucid very rounded quartz, and a few panidiomorphic phenocrysts of highly altered felspar in a micromosaic of quartz, felspar, sericite, iron oxides, biotite and pyrite. One rather rounded and broken crystal of slightly pink garnet occurs associated with a little biotite and muscovite. Irregular shaped grains of pyrite are seen replacing felspar in places in this section.

F.—Metasomatically altered rocks.

The dacites in the Healesville area are remarkably fresh, and except for the occasional presence of chlorite, epidote, sericite and very rarely tourmaline, they remain unaltered. It has been previously suggested that the dacitic lavas were very viscous and poor in mineralisers; hence, perhaps, the minor alteration of these rocks. The basal volcanic rocks,—the rhyolites, and tuffs,—however, have been greatly altered in places. These metasomatically altered rocks are best seen along the aqueduct from the Badger river, south-west of Mount Riddell. Here, a greenish-coloured, compact rock, veined with carbonates and quartz are locally greatly pyritised, outcrops. Examined under a lens, some of the limonitised pyrites appears to contain native gold. In the absence of assays of the pyrites, however, one cannot assert definitely that gold is present in these rocks. The fact that gold has been won from the Badger creek, near by here, is perhaps significant. According to Professor Skeats, gold has been obtained from creeks passing only over dacites near Marysville and Gembrook, but its mode of occurrence is not known.

Specimen No. H80, from south-west of Mount Riddell, is typical of these propylitised rocks. Hand specimens are compact and aphanitic, and of a greenish-grey colour. The specific gravity of the rock is 2.80. Examined microscopically it is seen that the original rock has been greatly replaced by carbonates, chlorite, sericite and pyrites, much of which has been oxidised to limonite and hematite. One large, simply twinned, phenocryst of orthoclase remains. It is partly replaced by sericite and granular chlorite and a little carbonate.

Other idiomorphic felspar crystals are seen to be entirely replaced by carbonates, chlorite (pennine), and sericite. The quartz phenocrysts still remain clear, although greatly corroded and partially sericitised in places. Small lenticular vesicles, infilled with carbonates and quartz, are occasionally present. Veinlets of carbonates, chlorite and a little quartz traverse the rock. Carbonates are abundant throughout the ground mass of the rock, especially replacing felspar laths. The alteration of the tuffs and agglomerates, that occur near by here, has been previously described.

Near the Echo tunnel, in the Maroondah aqueduct, and also near the Maroondah weir, carbonation, sericitisation and pyritisation have taken place in the basal volcanic rocks underlying the normal dacites.

Secondary tourmaline and biotite have been mentioned as forming in the rhyolites near Archer's Look-out, and in the tuffs near here fluorite is occasionally present.

This alteration has been ascribed by the writer to the action of vapours released from the neighbouring granodiorite.

5.—Field Relations and Origin of the Igneous Rock.

A.—Relationship of the granodiorite to the sedimentary and volcanic rocks.

Wherever seen the granodiorite is intrusive into the Silurian sediments, and has altered the latter for some distance from the junction. Xenoliths of hornfels are also common in the granodiorite near the contact.

The relationship of the plutonic rock to the igneous rocks, however, is not so evident. Selwyn stated that hornblende granite passed into porphyry near Mount Monda, and Ferguson also believed that there was a gradual passage between the plutonic and volcanic rocks near Gembrook.[1] However, Professor Skeats has shown clearly that near Gembrook and Macedon, the granodiorite is intrusive into the normal dacite, and that the latter rock has been rendered gneissic in places near the contact. Whenever the two rocks come into relation in the Healesville area marked con-

1 "Notes on certain Geological Features of the Parishes of Gembrook North and Nangana." Prog. Rept. Vict. Geol. Surv., No. 8, 1894.

tact alteration of the dacite is usually absent. However, near Nyora the dacite contiguous with the granodiorite has been rendered gneissic, and in the ranges to the west of Narbethong a gneissic dacite was seen by the writer near the contact with granodiorite. Clearly, in the Healesville district as elsewhere in Victoria, the intrusion of the granitic rock took place after the extrusion of the dacite.

Near Malory's falls rhyolite is apparently superposed on granodiorite. No alteration of the rhyolite near the contact is visible in hand specimens. However, thin sections of the rhyolite show the development of secondary biotite and blue tourmaline, and the writer attributes this alteration to the action of vapours given off from the cooling plutonic rock. Fluorite has also been formed in the tuffs near Malory's falls. More certain evidence of the subsequent intrusion of the granodiorite, e.g., apophyses or dykes from it passing into the rhyolites was not obtainable. In the sequel, it will be shown that the dacite is younger than the rhyolite, adding further support to the sequence suggested above.

Secondary biotite has also been formed in the obscure flinty rocks, probably rhyolites, from near Mount St. Leonard. Granodiorite outcrops on the east bank of Meyer's creek, close by here, and it is probable that the alteration in the rhyolite was brought about owing to the intrusion of the plutonic rock.

B.—Relationships of the volcanic rocks to one another.

That the pyroclastic rocks were associated with the rhyolitic outburst, and were previous to the dacitic activity is certain from the following facts:—

1. Everywhere in the area, the tuffs occur marginal to the dacites, and clearly underlie them at certain points.

2. Near Wade's Look-out and Badger weir, quartz porphyry and rhyolite pebbles and lapilli, from the agglomerates and tuffs, are often seen to have been caught up in the lowest layers of the dacite.

3. The tuffs throughout the area are composed of rhyolitic debris, and andesitic or dacitic ejectmenta are generally absent from them.

A traverse up the Acheron river from St. Fillans shows that the dacites overlie the rhyolites in this area. The latter rocks, which, near their contact with the Silurian sediments contain little biotite, become richer in this mineral close to the dacites, yet, they appear to be sharply defined from one another. The superposition of the dacites on the rhyolites near the Acheron River, and the inclusion of fragments of the latter rock in the former at certain places, are sufficient to prove the subsequent extrusion of the dacites. The position of the quartz free andesites is not certain. They occur marginal to the dacites near Launching Place, suggesting that the latter rocks overlie them. Numerous xenoliths of andesite occurring in the Blacks' Spur dacite, may also indicate a subsequent origin for the dacite. However, in the absence of more certain evidence it is better to leave the question of the age of the andesites unanswered. The evidence brought forward is sufficient to establish the following sequence, from older to newer—

Rhyolites and rhyolitic tuffs,
Andesite,
Dacites,
Granodiorite.

The sequence, viewed broadly, shows the order of extrusion to be one of increasing basicity.

C.—*Origin of the rocks.*

Without much doubt all these rocks have been derived by differentiation from a common magma. Whether the differentiation is of a serial or complementary type, cannot however be determined with certainty in the absence of chemical analyses of all these rocks. The question of differentiation has been attacked exhaustively in the Macedon area by Professor Skeats and Dr. Summers, and at Dandenong, by Mr. Morris, and their conclusions leave no room for doubting that the granodiorites and dacites in these areas are consanguineous. If any further evidence is needed in the Healesville area to establish the comagmatic origin of the rocks, the striking similarity in their mineralogical composition and their intimate association in the field may be put forward in support of this view. Especially significant is the occurrence of zone plagioclase and microperthitic orthoclase in the granodiorite, and exactly the same types of felspar in the dacites and rhyolites. Garnet is also present in all of these rocks.

6.—Conclusions.

1. Folded Upper Silurian shallow water marine sediments form the basal beds of the Healesville area. Fossils are rare. Haliserites Dechenianus, Göppert, was found in the north of the

area, determining the age of the beds as probably Tangilian. Poorly preserved corals and crinoids, occur in conglomerates from near Narbethong.

2. The vulcanicity in this area commenced in ? Devonian times, after the folding and uplift of the sediments. Extrusion of rhyolites, accompanied by minor explosive outbursts, inaugurated the cycle of volcanic activity. The expiring rhyolitic vulcanicity was marked by the passage of hydrothermal solutions, containing alkaline carbonates and sulphides, in solution, through the previously consolidated igneous rocks.

3. A great thickness of dacitic rocks, including quartz free andesites, biotite dacites, and hypersthene biotite dacites succeeded the rhyolites and pyroclastic rocks, and covered up most of them. The latter rocks are now only visible around the periphery of the dacites, where denudation has been greatest. There is good reason to believe that the dacitic magma was very viscous. Steam cavities are almost entirely absent, and mineralisers which would have decreased the viscosity were apparently scarce.

Later still, granodiorite was intruded at several points. Subsequent denudation, which has been greatest around the margins of this volcanic pile, has exposed certain of these intrusions.

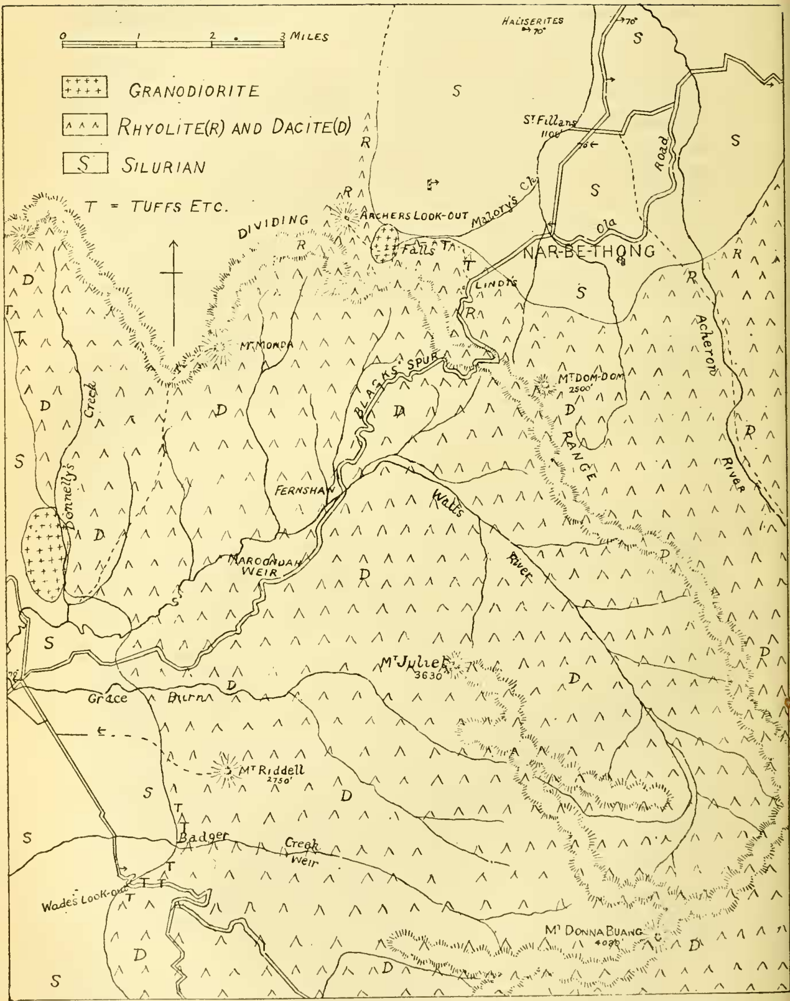
The volcanic activity appears to have been entirely sub-aerial. There is no evidence present anywhere in the area of lacustrine or marine sediments associated with the igneous rocks.

4. It is very probable that all the igneous rocks described are congeneric. The more complete evidence available from other areas in Victoria, e.g., Macedon and Dandenong, where somewhat similar rocks are present, supports this belief. The sequence of eruption was apparently one of increasing basicity.

5. Magmatic fusion and assimilation of aluminous rocks by certain of the dacites has taken place, and as a result cordierite, sillimanite and, possibly, garnet, have been formed.

6. The origin of the garnet remains unsolved, but it seems very likely that it is a primary mineral in the rocks. Its extensive occurrence, in granites, porphyries and dacites elsewhere in Victoria, supports this contention.

In conclusion, the writer desires to express his indebtedness to Professor Watts, for many facilities granted him in the carrying out of this research at the Royal College of Science, London; and to Professor Skeats, for advice and suggestions.



Geological and locality sketch map of the Healesville and Narbethong area. The junctions of the rhyolites and dacites are not shown owing to the mapping of their boundaries not being completed.

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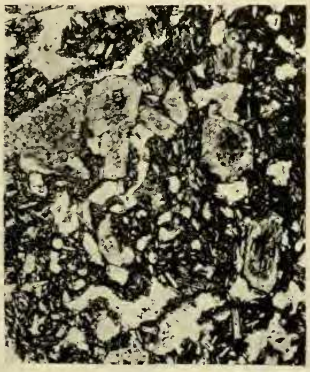

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